Evaluation of Uncertainty in Satellite Monthly Aerosol Products Associated with Spatial Sampling

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A preliminary investigation on the quality of temporal and spatial aggregated data from satellite Level 3 daily aerosol products with large amounts of missing data.

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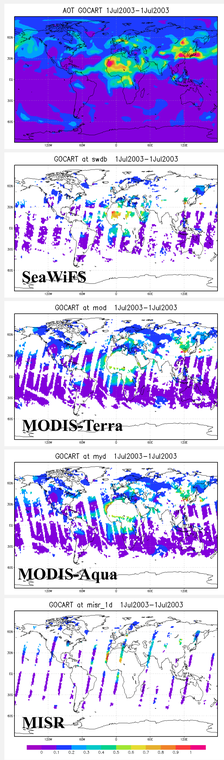
Abstract

Large amounts of data are frequently missing from global satellite daily aerosol products, due to limitations of both the satellite sensor and data retrieval algorithms. Missing data can be caused by orbital gaps, cloudiness, and snow/ice, etc. Wave-like artifacts were observed in MISR monthly products due to large data gaps associated with its narrow orbit. As monthly mean products are popular for use in research on long term climate trends, this study has investigated uncertainty in the monthly mean caused by spatial sampling. Using daily data from the NASA Goddard Chemistry Aerosol Radiation and Transport (GOCART) model, data gaps in four satellite products are simulated. Comparing monthly data from the original and gap-simulated model data, statistically significant differences are found due to spatial data sampling.

Data

- 5 years (2003-2007), completely spatial covered, daily aerosol optical thickness (AOT) from GOCART, (AOT = sum(BC+POM+DU+SS+SU)), bilinear interpolated from 2x2.5 deg to 1x1 deg resolution
- Daily GOCART AOT data are sampled by simulating missing data points on four satellite daily products: SeaWiFS Deep Blue (SWDB), V4; MODIS (Terra and Aqua) Dark Target V5.1; and MISR V4, where MISR data are aggregated from 0.5 to 1.0 deg. (Sample images at left below.)
- Monthly data are calculated by averaging the daily original and missing data simulated for each sensor. (Sample images on the right below.)

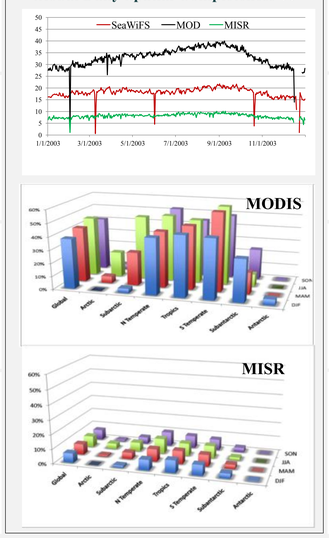
Daily Data



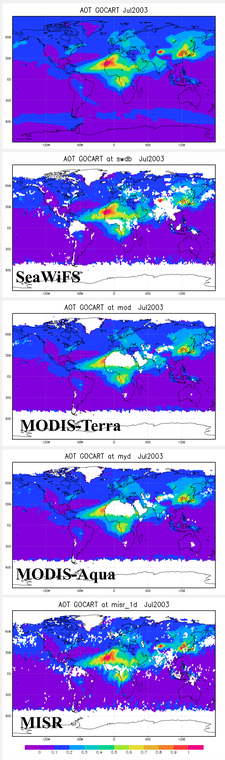
Daily Spatial Completeness:

Time series and images below show the daily spatial completeness (valid data point ratio) of AOT, ~25-40% from MODIS, ~15-23% from SeaWiFS, and only ~ 5-10% from MISR on the global scale, varying regionally, and varying slightly with seasons and years.

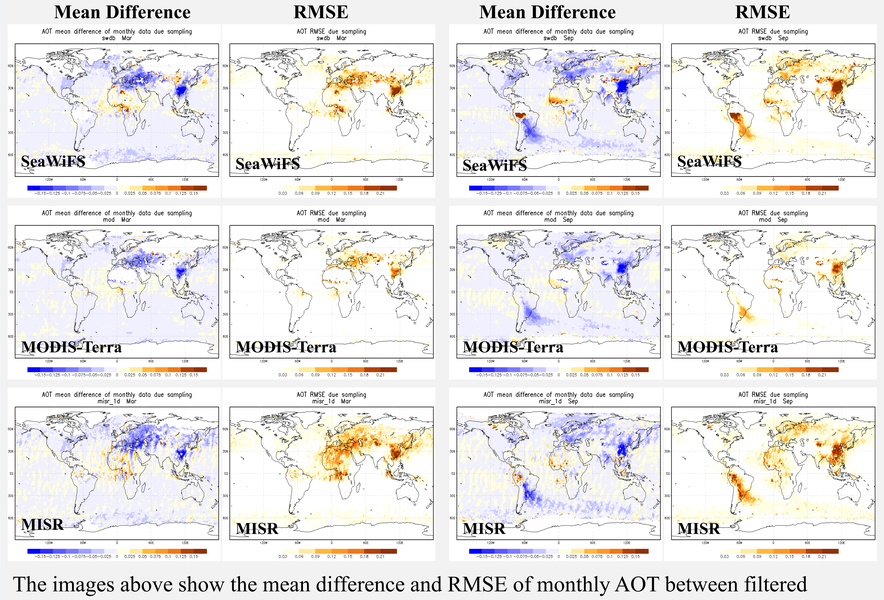
Global Daily Spatial Completeness %



Monthly Data



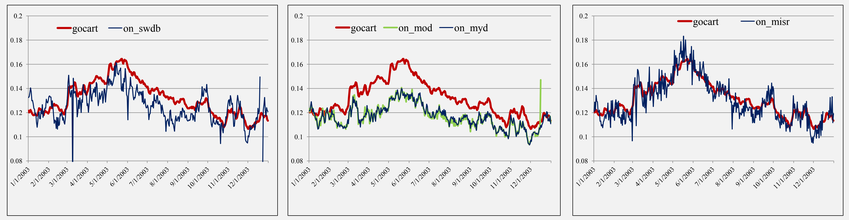
Differences in Monthly Mean



The images above show the mean difference and RMSE of monthly AOT between filtered (missing data simulated) and original data for March and September, averaged for five years for SeaWiFS, MODIS-Terra, and MISR, respectively. Results from MODIS-Aqua are very similar to MODIS-Terra and thus are not shown here. Although the daily data sampling is quite different among four satellite products, in general, the patterns of mean difference and RMSE are similar to a certain extent. Large differences are mostly over land. **Monthly data coverage (when composed from the daily data with simulated missing data) is likely underestimated in many regions (blue regions),** with maximum differences of ~30%. The Mean Difference and RMSE have **seasonal variations**, as indicated in March and September.

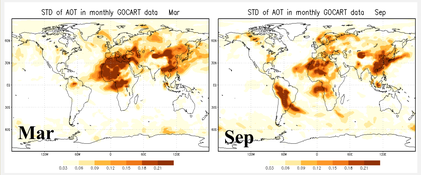
Comparing Global Mean Time Series

The time series below are the global mean AOT of GOCART original daily data (red lines), and simulated missing data on each sensor for the year 2003. The uncertainty of global daily mean AOT has a negative relationship to the spatial completeness, i.e., uncertainty increases as the spatial completeness of the data set decreases (from MODIS to SeaWiFS to MISR). Significant negative bias is found in the global mean of missing-data-simulated AOT on_MODIS, in particular March-September, but is smaller on_SeaWiFS and not seen on_MISR. This is largely due to the lack of coverage over deserts in the MODIS Dark Target data set. Interestingly, although the spatial completeness is smallest for MISR data, there is less systematic bias in global mean AOT on_MISR than that on_MODIS and on_SeaWiFS.



Discussions

Standard Deviation of AOT



Temporal Variability:

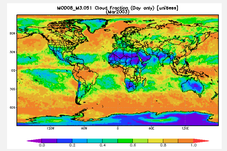
Images at left: Averaged standard deviation, calculated from GOCART daily AOT for a month, indicating temporal variability within a month. It is noted that significant mean differences appearsover regions where the monthly temporal variability is relative large, such as over East Asia in both months associated with dust and pollution, and over South America in September due to biomass burning.

Spatial Distribution of Data Sampling :

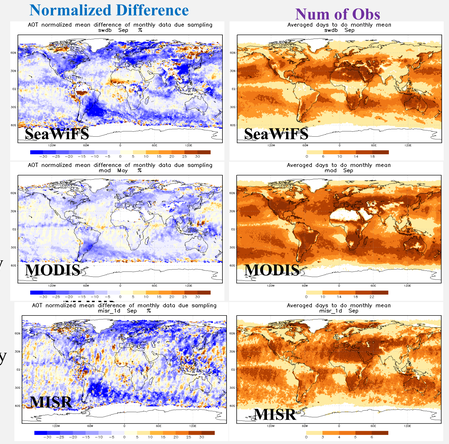
Images are the monthly **normalized difference** (lower left), **number of observations** in a month to compose the monthly mean (lower right), and daytime **cloud cover** from MODIS for September (right).

It is noted that large differences are mostly at the locations where the number of observations are low for the data subsampled on all sensors. This feature is seen better in the normalized difference. Note, the number observations are plotted in different scales to better display the spatial pattern.

Cloud Cover



Normalized Difference | **Num of Obs**



The pattern of the monthly number of observations is found to be similar to monthly cloud cover, indicating that large missing data from cloudiness may cause significant bias when composing a monthly product.

Missing data from gaps between swaths may increase the uncertainty of the monthly mean. For example, the narrow swath in MISR may produce a wave-like pattern.

Summary

Using five years of daily AOT data from the GOCART model, missing data are simulated for four Level 3 daily products from SeaWiFS, MODIS (Terra and Aqua), and MISR. Comparisons between data from original model data and gap-simulated data show the following results:

- The monthly mean AOT sampled by satellite is underestimated in many regions, with the largest bias of ~30%.
- The large differences are likely due to missing data associated with persistent cloudiness. The location of large differences varies seasonally, similar to the persistent cloudiness.
- The pattern of the difference is in general similar in all tested sensors, indicating that merging data from multiple sensors (if all are retrieved from visible channels) may reduce errors in the monthly mean, but to a limited extent as the missing data from persistent cloudiness can not be removed completely.
- Uncertainty of the area mean AOT by satellite observation increases as spatial completeness decreases, but may not increase the systematic bias.

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